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(54) **Tomo-scanner and image scanning and reconstruction method used for such a tomo-scanner**

(57) In a translation - rotation - type tomographic scanner there is provided a radiation source (S), n detectors ($d_1, d_2, d_3 \ldots d_n$) receiving n juxtaposed elementary beams ($f_1, f_2, f_3 \ldots$) of angular aperture α, the useful beam F having an angular aperture $\Phi = n\alpha$ and means for the combination of signals belonging to n.p consecutive elementary projections obtained during p successive translations so as to obtain from the superabundant number N of angular samples supplied during a rotation of π radians of the source - detector assembly, the number N_o (less than N) of angular samples necessary and adequate for the reconstruction of the image.

FIG.3

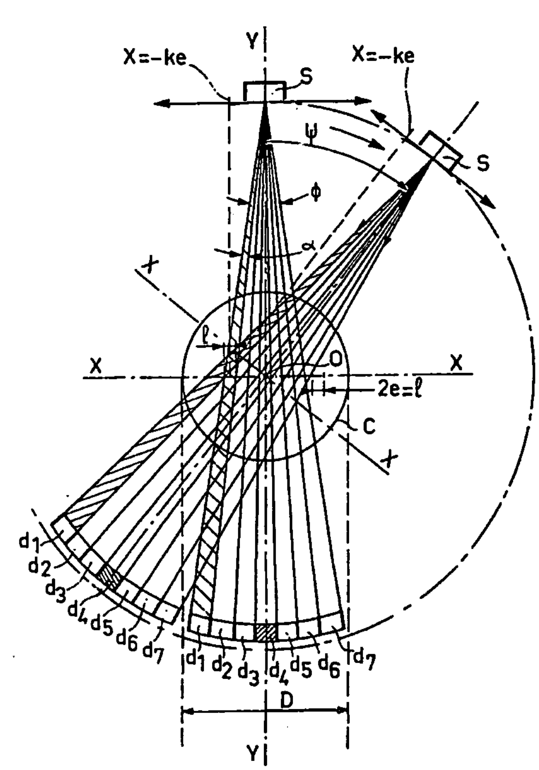

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FIG. 1

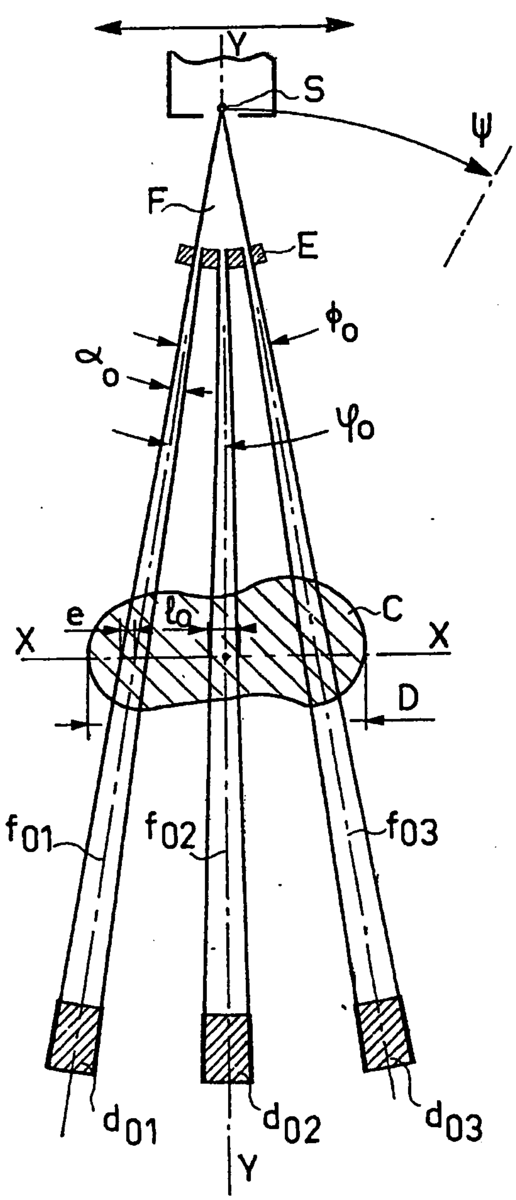

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FIG. 2

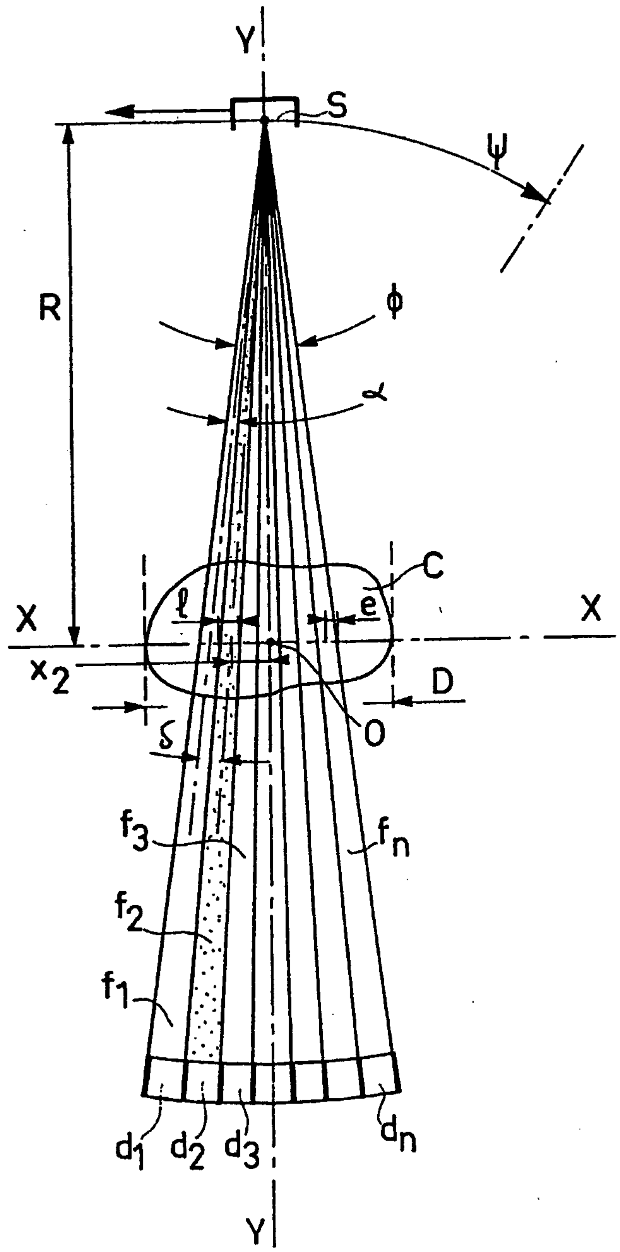

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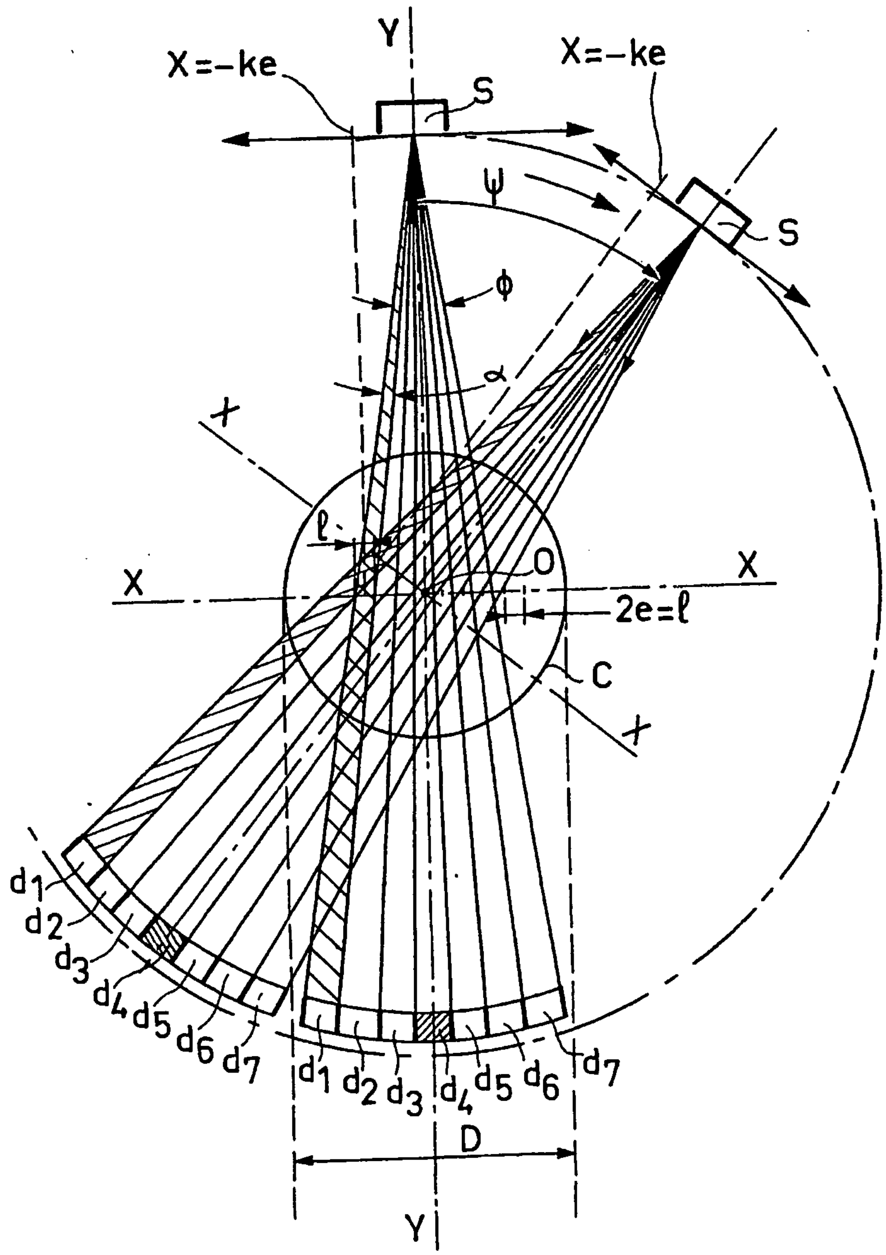
FIG.3



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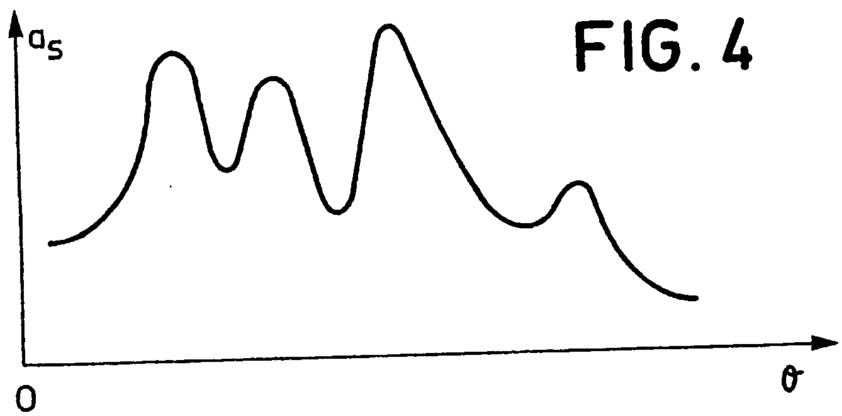

FIG. 4

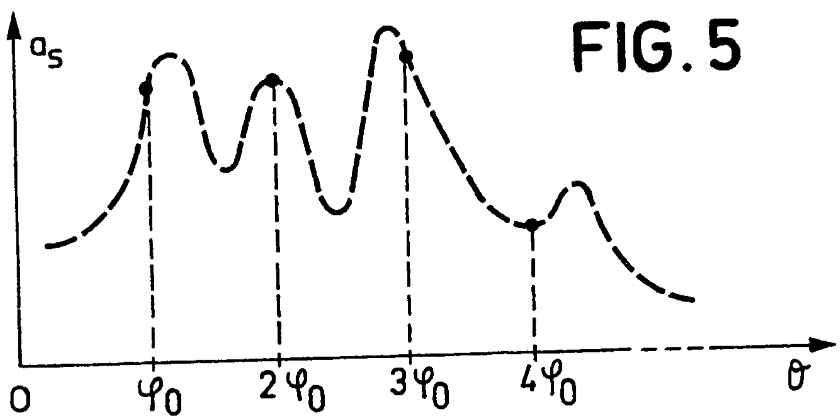

FIG. 5

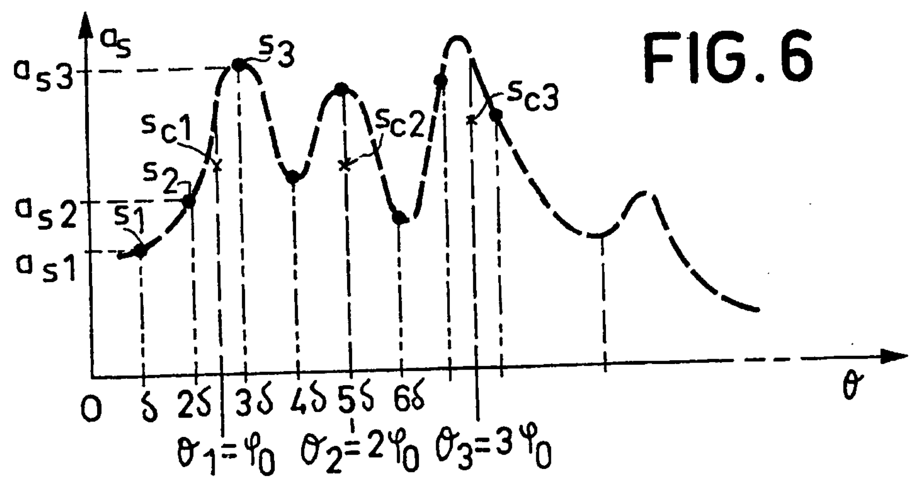

FIG. 6

SPECIFICATION

Tomo-scanner and image scanning and reconstruction method used for such a tomo-scanner

The present invention relates to a tomo-scanner of the translation-rotation type supplying radiographic data making it possible to reconstruct the values to be examined.

In a known construction, a tomo-scanner has an assembly comprising a source and detectors, said assembly undergoing on the one hand a succession of linear translations and on the other hand a series of elementary rotations in a sectional plane, a rotation taking place between two successive translation sequences.

In order to speed up the image reconstruction operations with respect to an object to be examined it is known to use a series of detectors which may be combinations of scintillators and photodetectors or ionization chambers for example. The radiation beam (X or Y rays) emitted by the source and which is shaped like a fan being subdivided into elementary pencils by means of a slit collimator positioned upstream or downstream of the object to be examined. The number of these elementary pencils corresponds to the number of detectors. It is the width of the said radiation pencils which limits the modulation transfer function of the system, i.e. its spatial resolution.

It is pointed out that narrow pencils make it possible to obtain a good spatial resolution. However, if the number of photons received by each of the detectors is too low, the extent of the quantum noise can be prejudicial to the quality of the results obtained.

The tomo-scanner according to the invention does not have the aforementioned disadvantages and makes it possible to obtain a very detailed final image by means of an undivided beam and, in addition, makes it possible to adapt the angular pass band so that it corresponds to the desired angular sampling.

The present invention therefore relates to a tomo-scanner of the translation-rotation type for the examination of an object C and incorporating a source S supplying a useful beam F of radiation and rigidly connected to the said source S there is a series of n detectors, each associated with a measuring system relative to the detected signals and each of them receives a fraction of the useful beam F of radiation, means for successive displacements in translation and rotation of the source-detector assembly, each of the detectors supplying during each translation n signals, the totality of said n signals constituting an elementary projection of object C, wherein the n detectors are contiguous and receive in each case one of the n elementary beams which are juxtaposed fractions of beam F, of angular aperture ϕ, said n detectors supplying during one translation M.n signals constituting n elementary projections of objects C and during p successive combinations corresponding to p-1 sequential rotations of angle $\Delta\psi = \phi$ of the source-detector assembly M.n.p signals, and wherein signal combination means make it possible to obtain from said M.np elementary signals corresponding to n.p consecutive elementary projections, m groups of Q signals, said Q signals being obtained by combinations of signals taken from among said M.n.p signals, said M groups constituting m projections-combinations intended for reconstituting the image of object C.

The invention is described in greater detail hereinafter relative to non-limitative embodiments and with reference to the attached drawings, wherein show:

Fig 1 diagrammatically a known tomo-scanner.

Figs 2 and 3 diagrammatically a tomo-scanner of the translation-rotation type according to the invention for different positions of the source-detector assembly.

Figs 4, 5 and 6 diagrams showing in exemplified manner the amplitude a_s of signals detected as a function of the projection angle Θ of the object C to be examined, respectively in an ideal device with continuous measuring, in a prior art device and in the device according to the invention.

The known tomo-scanner of the translation-rotation type shown in Fig 1 comprises a radiation source S supplying a useful beam F of radiation (e.g. X-rays) which, after primary collimation by means of a collimator E, i.e. a collimation performed between source S and an object C to be examined, is subdivided into a plurality of elementary pencils f_{01}, f_{02}, f_{03} . . . of angular aperture α_0 and width 1_0, said width 1_0 being considered in a mean plane perpendicular to beam F (and intersecting the plane of the drawing along axis XX of the object C to be examined).

The bisectors of two consecutive elementary beams f_{01}, f_{02} or f_{02}, f_{03} . . . form between them an angle φo. The value of 1_0 limiting the pass band of the known tomo-scanner is chosen as a function of the desired spatial resolution, i.e. the fine detailed resolution of the desired image. Thus, the value of 1_0 imposes a value e of the linear sampling period which must be compatible with the sampling theory (Shannon's law) which states that e must at the most be equal to $1_0/2$, which means that the linear sampling frequency must at least be equal to double the maximum frequency to be transmitted. Moreover, it is necessary for there to be clearly defined relationships between the number of linear samples M = D/e (D being the diameter of the scanned field in the sectional plane) and the number N_o of angular samples obtained during one rotation of -/N_o radians of the source-detector assembly, i.e. the number of projections of the object C to be examined necessary for the reconstruction of the image in a given sectional plane, which corresponds to successive projections separated by an angle -/N_o radians. In the prior art tomo-scanner, it is necessary for the angle φo to be equal to π/N_o, the angular sampling being defined during one and the same translation by the angular arrangement of the detectors. The disadvantages of such a construction are, on the one hand, the incomplete utilization (due to the presence of collimator E) of the useful beam F of radiation, the angle α_0 then being less than the angle φo and on the other hand an angular sampling which is not suitable for the angular pass band limited by the angular aperture α_0

below φo.

The tomo-scanner according to the invention does not have these disadvantages and permits a very satisfactory angular samplir... whilst using the total of said useful beam F of chosen angular aperture.

In one constructional embodiment, the tomo-scanner shown in Fig 2 of the translation-rotation type has a radiation source S supplying a useful beam F of radiation (e.g. X-rays), a series of n contiguous detectors $d_1, d_2, d_3 \ldots d_n$, having partitions of minimum thickness. These n detectors $d_1, d_2, d_3, \ldots d_n$ are each intended to receive a fraction of the useful beam F, i.e. n elementary beams $f_1, f_2, f_3 \ldots f_n$, having the same angular aperture α. Thus, the useful beam F has an angular aperture $\phi = n\alpha$. These detectors $d_1, d_2, d_3 \ldots d_n$ are rigidly connected to source S and placed in a same plane as said source S and the useful beam F, said plane defining a sectional plane of the object C to be examined (plane of Fig 2).

In practice, n is chosen in the following way. For a field to be scanned of diameter D (D = e.g. 250 mm), a maximum spatial frequency ν_M to be transmitted by the device according to the invention will be chosen. This means on the one hand that it is necessary to use the maximum width 1 of the elementary beam considered in the mean plane defined hereinbefore and on the other hand a value e of the linear sampling period compatible with Shannon's law. If R is the distance separating the source S from the mean plane of the object C to be examined, it is possible to deduce therefrom the angular aperture $\alpha = \text{arc tg}\frac{1}{R}$ of the elementary beam and, for a selected number n of detectors, the angular aperture value $\phi = m.\alpha$ of the useful beam F of radiation.

Fig 2 shows the position of the source-detector assembly during a translation for an angle ψ of given rotation.

During this translation, each of the detectors $d_1, d_2, d_3 \ldots d_n$ supplies M = D/e linear samples, which determine an elementary projection of the object C to be examined in accordance with a projection angle ϕ determined on the one hand by the angular position ψ of the source-detector assembly and on the other by the angular position occupied by the considered detector d_1 or $d_2 \ldots$ or d_n in the useful beam F.

In operation, the successive beams $f_1, f_2 \ldots f_n$ of angular aperture α and separated from one another by an angle $\delta \simeq \alpha$ make it possible to obtain an angular sampling of pitch $\delta \simeq \alpha$. If, between each translation sequence the source-detector assembly rotates by an angle $\Delta\psi = n\delta$, after $\frac{\pi}{n\delta} - 1$ rotations of $\Delta\psi = n\delta$ radians each (Fig 3), a group of $N = \pi/\delta$ elementary projections will be obtained, N being greater than the number N_o of projections defined hereinbefore.

Whereas, in the prior art devices, it was necessary for the angle separating two successive collimated beams of angular aperture αo (Fig 1) to be equal to $\varphi o = \frac{\pi}{N_o}$ for the requirements of the reconstruction calculation, in the device according to the invention the elementary projections obtained are separated by an angle δ substantially equal to the angular aperture α of the elementary beams $f_1, f_2, f_3 \ldots f_n$, δ thus being less than φo because said elementary non-collimated beams $f_1, f_2, f_3 \ldots f_n$ are contiguous. In the device according to the invention each of the n detectors $d_1, d_2 \ldots d_n$ respectively associated with means for measuring the detected signals supplies during each translation M measuring signals, i.e. in all M.n measurements constituting n elementary projections of the object C to be examined, in a given sectional plane in accordance with angles spaced by δ.

During one rotation of an angle π of the source-detector assembly, a superabundant number $N = \frac{\pi}{\delta}$ of elementary projections is obtained. Signal combination means then make it possible to combine together signals taken from among the M.n.p signals obtained for p consecutive elementary translations in such a way that m groups of Q signals are obtained supplying m projections-combinations (m < p) which can be used in the reconstruction of the image of object C to be examined. The combination process is chosen in such a way that on the one hand all the collected signals are used and that on the other the total number of projections-combinations obtained in this way is substantially equal to N_o.

The curves of Figs 4 and 5 represent for the same object C, the amplitudes of the signals obtained at the abscissa point x = ke, x being measured with respect to point O, the centre of the central sample, as a function of the projection angle Θ, and k being a positive or negative integer. More specifically, Fig 4 shows the amplitudes a_s of the signals obtained for a variable angle Θ in the ideal case where δ and α are infinitely small (continuous measurement). Fig 5 shows the amplitudes a_s of signals obtained in a prior art tomo-scanner, the angular aperture α_o of an elementary beam being small compared with the angle φo separating the bisectors of two successive beams (Fig 1), said amplitudes being equal to those indicated in Fig 5 for the angles $\Theta = \varphi o, 2\varphi o, 3\varphi o \ldots$ and only at these values, the other points of the curve not being accessible. It is pointed out that the group of amplitudes a_s of signals obtained in this way does not represent a satisfactory sample because $\varphi o >> \alpha$.

Fig 6 shows on the one hand the amplitudes a_{s1}, a_{s2}, a_{s3} of the signals s_1, s_2, s_3 corresponding to angles $\psi = \delta, 2\delta, 3\delta \ldots$ such that the difference between two of these consecutive angles is equal to the angular aperture α of the elementary beams (these amplitudes being indicated by dots on the curve in Fig 6) and on the other hand the amplitudes a_s of signals $s_{c1}, s_{c2} \ldots$ (marked by across) obtained by the combination of signals s_1, s_2, s_3 of measured amplitudes a_{s1}, a_{s2}, a_{s3} (and represented by dots) and corresponding to elementary projections of angles $\Theta_1 = \varphi o$, $\Theta_2 = 2\varphi o$, $\Theta_3 = 3\varphi o \ldots$

The amplitude value a_s of each of the signals obtained in this way by combination is taken for a value of the sample corresponding to the same abscissa x = ke of the projection-combination of angle Θ_i, said angle being located in the angular interval of the elementary projections used for obtaining the

projection-combination in question. By repeating the same process of combinations for all the angles of the elementary projections on the one hand and on the other for all the abscissas $x = ke$, it is possible to obtain the N_o projections-combinations spaced by an angle substantially equal to φo necessary for calculating the image reconstruction. As a non-limitative example in Fig 6 an angular sampling angle of $\varphi o = 2.5\delta$ has been taken. The projection-combination corresponding to the signal s_{c1} (cross) is obtained by the combination of the elementary signals s_1, s_2, s_3 (dots) which are respectively supplied by detectors d_1, d_2, d_3, its sampling angle being $\Theta_1 = 2.5\delta$, whilst the sampling angles of the elementary projections corresponding to signals s_1, s_2, s_3 are respectively δ, 2δ, 3δ.

For the same abscissa $x = ke$, signal s_{c2} belonging to the following projection-combination is obtained in the same way, which will thus have for the sampling angle $\Theta_2 = 2\varphi o = 5\delta$. Between two successive projections-combinations, there will be an apparent angle $\Theta_i - \Theta_{i-1} = \varphi o = 2.5\delta$, i.e. equal to the desired angular sampling pitch satisfying the ratio $\varphi o = \frac{\pi}{N}$.

A number of known methods can be used for obtaining a projection-combination from elementary projections, i.e. linear combinations, non-linear combinations such as interpolations, or an adaptation of a function by estimation methods, such as the method of least squares for example.

Another advantage of the device according to the invention is that it reduces the noise which can affect the measurements. This advantage is particularly marked if the combination of signals in non-linear and involves an elimination of the non-coherent values.

Whatever the combination method used making it possible to obtain an apparent sample of period φo, it should be noted that the utilization level of the useful beam F of angle ϕ emitted by the source is substantially equal to 100% (α/δ substantially equal to 1), whilst in the prior art devices, the utilization level of beam F is only approximately 25% ($\alpha_o/\varphi o = 0.25$).

In order to completely utilize the thus obtained combination signals for each projection-combination, all the elementary projections of an angle between at least $\Theta - \delta/2$ and $\Theta + \delta/2$ are used. Thus, all the measurements performed are used, so that the sampling conditions are improved. In a particular case where $\varphi o = 2\alpha$, the projection-combination can be taken as the sum of two consecutive elementary projections having an apparent sampling angle equal to the arithmetic mean of the sampling angles of the consecutive elementary projections used.

It is pointed out that if a more strict sampling is required, it is possible to use as the elementary projection the projections in an interval at least equal to 2δ. For example, it is possible to obtain a weighted sum with maximum coefficients in the vicinity of the sampling angle allocated to the projection-combination and coefficients whose values decrease progressively whilst substantially following a law of the Laplace-Gauss type when there is an increase in the angular difference between the other sampling angles and said allocated sampling angle.

CLAIMS

1. A tomo-scanner of the translation-rotation type for the examination of an object C and incorporating a source S supplying a useful beam F of radiation and rigidly connected to the said source S there is a series of n detectors, each associated with a measuring system relative to the detected signals and each of them receives a fraction of the fuseful beam F of radiation, means for successive displacements in translation and rotation of the source-detector assembly, each of the detectors supplying during each translation n signals, the totality of said n signals constituting an elementary projection of object C, wherein the n detectors are contiguous and receive in each case one of the n elementary beams which are juxtaposed fractions of beam F, of angular aperture ϕ, said n detectors supplying during one translation M.n signals constituting n elementary projections of objects C and during p successive combinations corresponding to p-1 sequential rotations of angle $\Delta\varphi = \phi$ of the source-detector assembly M.n.p signals, and wherein signal combination means make it possible to obtain from said M.n.p elementary signals corresponding to n.p consecutive elementary projections, m groups of Q signals, said Q signals being obtained by combinations of signals taken from among said M.n.p signals, said M groups constituting m projections-combinations intended for reconstituting the image of object C.

2. A tomo-scanner according to claim 1, wherein the n elementary beams (f_1 f_2 . . . f_n) have the same angular aperture $\alpha = \phi/n$.

3. A tomodensitometer according to claims 1 or 2, wherein the signal combination means comprise a system for the linear combination of detected signals coming from consecutive elementary projections.

4. A tomo-scanner according to claims 1 or 2, wherein the signal combination means comprise a system for the non-linear combination of the detected signals coming from consecutive elementary projections.

5. A tomo-scanner according to claim 2, wherein the signal combination means comprise a system making it possible to combine the signals of consecutive elementary projections included in an angular interval at least equal to 2α.

6. A tomo-scanner according to claim 1, wherein the signal combination means comprise a system making it possible to obtain a weighted sum of the signals taking maximum coefficients in the vicinity of the sampling angle and allocated to the projection-combination and coefficients whose values decrease progressively substantially following a law of the Laplace-Gauss type when there is an increase in the angular difference between the other sampling angles and said allocated sampling angle.

7. A method for the scanning and reconstruction of the image of an object C to be examined, using a translation-rotation-type tomo-scanner according to any one of the claims 1 to 6, wherein it comprises the measurement detection of M signals detected by each of the n detectors (d_1, d_2 . . . d_n) respectively

associated with the n elementary beams ($f_1, f_2 \ldots f_n$) during each of the translations of the source-detector assembly, the bisectors of two consecutive elementary beams forming between them an angle δ substantially equal to the angular aperture α of each of the elementary beams, each of the translations taking place after a sequential rotation at least equal to $\Delta\varphi = n\phi$ of the source-detector assembly which, during a rotation angle π of source e-detector assembly corresponds to a superabundant number of angular samples substantially equal to $N = \frac{\pi}{\delta}$; the combination of signals appropriately chosen from among the M.n.p signals obtained during consecutive elementary translations $\pi/N_o, N_o$ which is less than N being the number of angular samples which is necessary and adequate for obtaining during the corresponding scanning a rotation of at least π radians of the source-detector assembly; and processing the m projections-combinations so as to permit the reconstruction of the image of object C.

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